OBSERVATIONS OF DISCRETE GALACTIC SOURCES WITH OSSE

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ABSTRACT. The Oriented Scintillation Spectrometer Experiment (OSSE) on the *COMPTON* Gamma Ray Observatory has undertaken comprehensive observations of many galactic sources since launch in April 1991. These include investigations of binary X-ray sources, pulsars, several transient X-ray sources observed as Targets-of-Opportunity, and Nova Cygni 1992. Multiple observations of the galactic center region were undertaken to map the diffuse galactic emission and study the several discrete sources in that region. An overview of the galactic source observations and selected results are presented.

1.0 **Introduction**

The OSSE instrument on the *COMPTON* Observatory mission has been used to undertake observations of a variety of galactic sources. OSSE covers the energy range from 50 keV to 10 MeV (see Johnson et al. 1993 for a detailed description of the OSSE instrument). The field-of-view of the OSSE detectors is large: 3.8^{o} x 11.4^{o} FWHM. This is a compromise between a small field-of-view that is better suited for discrete source observations, and a large field-of-view that is preferred for study of the diffuse emission from the galactic plane. Kurfess et al. (1993) presented preliminary results of OSSE galactic source observations,

OSSE observations normally consist of 2-3 week viewing periods (VP) during which the observatory was maintained in a fixed orientation in inertial space. This strategy was implemented in Phase 1 of the *COMPTON* mission to enable the large field-of-view EGRET and COMPTEL instruments to carry out a complete sky survey. The plan was followed from the start of the science program in May 1991 through March 1992, at which time the failure of the observatory tape recorders forced a conversion to real time data acquisition though the TDRS system. To make up for the limited real-time coverage through TDRS, most viewing periods for the remainder of Phase 1 were extended to three weeks. Until recently, TDRS provided about 65% real time data coverage, which included both OSSE spectral and high time resolution data. In addition, since March 1993, storage of 2-minute spectra in on-board memory during periods of no TDRS coverage has significantly enhanced the total spectral coverage for OSSE sources.

2. **Transients**

OSSE has been used to undertake observations of several transient sources as Targets-of-Opportunity. These have often followed the detection by BATSE of a galactic source which has gone into outburst. These sources include GX 339-4, 4U 1543-47, X-ray Nova Per = GRO J0422+32, and GRS 1008-57. GX 339-4 is a well known transient X-ray source and black hole candidate which exhibits hard and soft spectral states similar to Cyg X-1, and QPO behavior. The OSSE observations of GX 339-4 are discussed by Grabelsky et al. (1993). In this paper, we discuss the OSSE observations of GRO J0422+32.

GRO J0422+32 was discovered by BATSE in August, 1992 (Paciesas et al. 1992) and is the strongest galactic source observed by OSSE at 100 keV. OSSE viewed the source for 34 days spanning the period 11 Aug 1992 - 17 Sep 1992. The source reached a maximum intensity of about 3X Crab shortly after the start of the OSSE observations, and then decreased in intensity with an ~40-day e-folding time. The energy spectra obtained by OSSE are generally thermal in nature, and are well described by optically thin thermal bremsstrahlung spectra with a kT of ~100 keV. Two spectra are shown in Figure 1 for

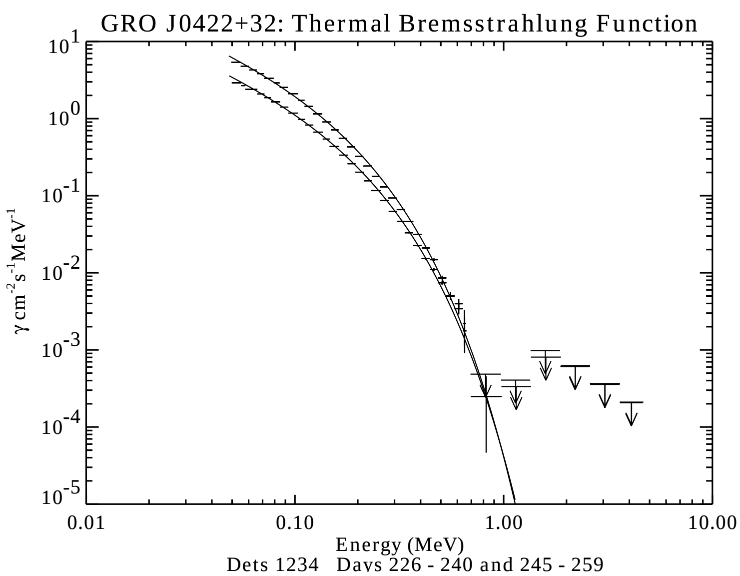

Figure 1. OSSE spectra for GRO J0422+32 from the first 16 days the observation (upper spectrum) and the last 18 days of the observation (lower spectrum). The spectrum hardens as the intensity decreases.

the first 16 days and the last 18 days of the OSSE observations. It is seen that the spectra harden with time, i.e. as the intensity of the source weakens. Of special interest is any evidence for persistent or time-variable annihilation radiation such as has been reported by the GRANAT/SIGMA experiment for Nova Muscae (Sunyaev et al. 1992; Goldwurm et al 1992) and 1E 1740.7-2942 (Bouchet et al. 1991). The OSSE data do not show any clear evidence for such features, with a limit relative to the continuum emission ~100 times less than the Nova Muscae line feature.

Grove et al. (1994) have presented preliminary timing analysis of the OSSE data on GRO J0422+32. High time resolution data were collected with 8-ms samples in five energy bands between ~35 and ~600 keV. Figure 2 shows the normalized power spectral density functions in the 35-60 keV and the 75-175 keV bands for the entire OSSE observation. The total fractional RMS variation between 0.01 Hz and 60 Hz is ~40% in the 35-60 keV band and ~30% in the 75-175 keV band. This is similar to the large variation reported by ROSAT in low energy X-rays (Pietsch et al. 1993). Grove et al. (1994) have modelled the power spectra as being composed of two classes of randomly occurring shots with characteristic e-folding times of ~50 ms and ~2.2 seconds and an additional component which produces the QPO-like peak at 0.23 Hz. The profile of the noise peak is rather broad compared to QPO phenomena observed in LMXRB's and this component accounts for an RMS variation of about 10%. Preliminary analyses of these data indicate that the fractional RMS power from the source increases as the source strength decreases. However, the frequencies of the peaked "QPO" component and the breaks in the power spectra near 2 Hz and 0.04 Hz do not change with the varying intensity of the source. More detailed modelling of the OSSE data are in progress.

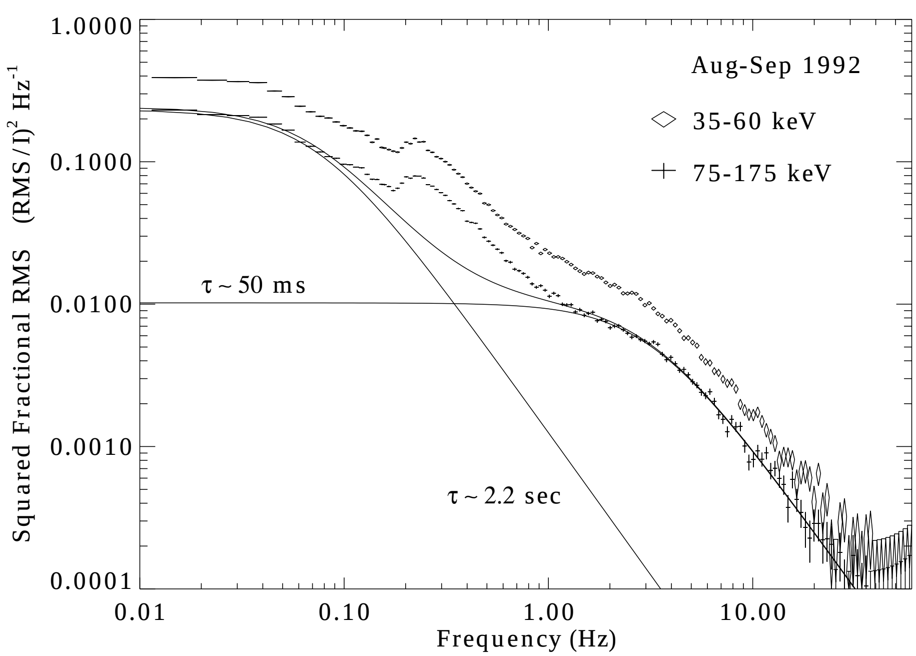

Figure 2. Normalized power spectra for GRO J0422+32 in 35-60 keV (upper) and 75-175 keV (lower) bands. Model fits (solid lines) to the 75-175 keV band includes exponential shots with lifetimes of 50 ms and 2.2 sec.

3. Cyg X-1

Cygnus X-1 has been observed frequently during Phase 1 and Phase 2 of the *COMPTON* mission. Significant exposure was obtained during viewing periods 2, 15, 203, 209 and 318.1. More limited exposures were acquired during VP 7, 212, 221, 223, and 303.4 All of the Cyg X-1 observations occurred when the source was near its lower intensity levels by historical standards. The spectrum is observed up to energies of about 800 keV and is well represented by an exponentially cut-off power law with corrections for compton reflection from cold gas (Phlips et al. 1994). Similar fits are also found for the other Cyg X-1 observations (Grabelsky et al. 1993).

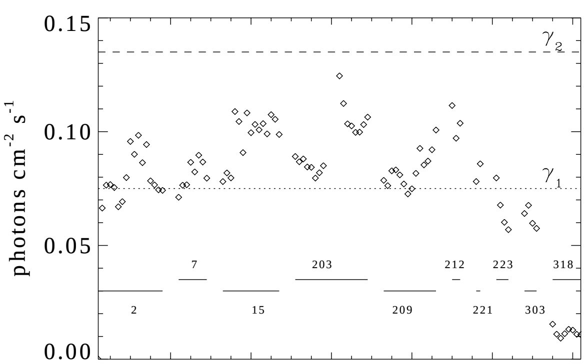

Figure 3. Daily 45-140 keV intensities from Cyg X-1 observed by OSSE. Viewing periods are labelled. Note that the time axis is not continuous. γ_1 and γ_2 states defined by Ling et al. (1987) are show.

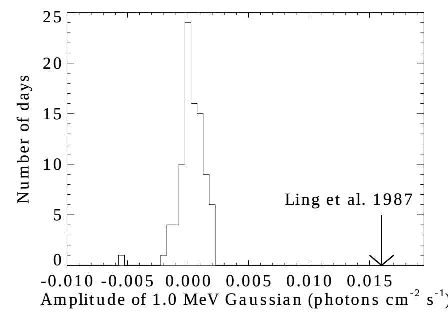

Figure 4. Amplitude for broad line at 1 MeV in addition to an exponential spectrum fit on a daily basis for all Cyg X-1 observations. The data are consistent with no MeV feature. The intensity of the line reported by Ling et al. (1987) is shown.

In June, 1993 BATSE reported (Harmon et al. 1993) a decrease in the intensity of Cyg X-1 which corresponded to a transition from the γ_2 state to the γ_1 state. These states were defined by Ling et al. (1987) who had reported a strong, broad MeV emission associated with the low intensity γ_1 state observed by the HEAO C1 spectrometer in 1979-1980. Such emission would be additional evidence for copious production of e^+e^- pairs in certain states of accretion onto galactic black hole candidates. Figure 3 shows the 45-140 keV intensity of Cyg X-1 for all of the OSSE observations, together with the γ_1 and γ_2 levels. The OSSE data show gradual intensity changes and no clear bipolar intensity levels which would clearly be attributed to different states. Many of the OSSE observations have been at intensity levels which are similar to the HEAO γ_1 level, including the observations in June, 1993. We have seen no evidence for excess MeV emission similar to that reported by Ling et al. (1987) in any of the OSSE observations. Figure 4 shows the distribution of MeV intensity levels above a best fit thermal bremsstrahlung spectrum and a comparison with the MeV flux reported by Ling et al. (1987). If the low intensity of the hard X-ray emission is taken as evidence for the γ_1 state with an accompanying MeV emission, the MeV component should have been present at levels ten times above the OSSE limits.

4. Cyg X-3

Cyg X-3 was observed during the four viewing periods VP 2, 7, 15, and 203.3. The VP 7 observation was undertaken as a Target-of-Opportunity following a major radio flare (Fiedler 1991) peaking at 17 Jy, which occurred in July 1991. This major flare was preceded by a smaller (5 Jy) flare in late June 1991. The VP 2 OSSE observation ended about one week prior to the precursor flare and the VP 7 observations occurred during the decay phase of the major flare when the radio emission had declined to below 2 Jy. The

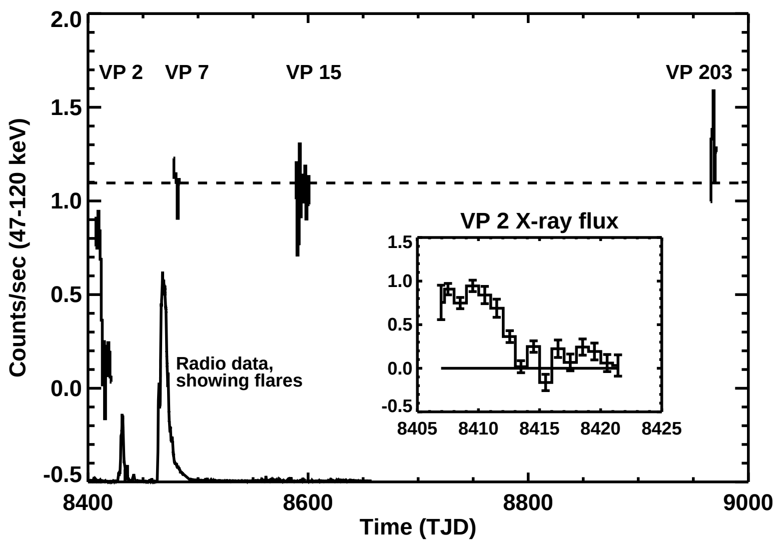

Figure 5. Daily average 47-120 keV intensities for four OSSE observations of Cyg X-3. The inset shows an expanded view of the decrease observed during VP 2. The 2.25 Ghz radio flux is also shown for temporal comparison with the decrease in intensity in hard X-rays.

OSSE data provided the opportunity to investigate any potential correlation between the radio flaring and the high-energy gamma-ray emission. Preliminary analyses of these data are reported by Matz et al. (1994a). Figure 5 shows the time history of the hard X-ray flux during the period of time covering the three OSSE observations. A dramatic decrease in the gamma-ray emission was observed during the VP 2 observation (prior to the precursor radio flare), dropping by a factor of three or more in a period of two days. The intensities during each of the latter observations, which occurred during the decay phase of the radio flare and during a radio quiet period respectively, were higher and relatively constant. The spectrum of Cyg X-3 during the low intensity state was considerably harder (α = 2.2±0.4) than the spectrum in the high intensity state (α = 3.0 ±0.1). It is not clear whether there is any connection between the gamma-ray variability observed and the radio flaring. It is most plausible that radio flaring would be delayed from the higher energy activity, which is presumably indicative of processes much nearer to the central compact object.

5. Galactic Center Sources

The galactic center region was observed for a total of 17 weeks during Phase 1 of the mission. These observations have several objectives, including mapping the distribution of the 0.511 and 1.809 MeV emission, mapping the diffuse galactic continuum emission which is primarily due to contributions from electron bremsstrahlung and inverse compton scattering by cosmic ray electrons, searching for evidence of variable point source(s) of 0.51 MeV emission, and the detection and study of other discrete low-energy sources in the region. Purcell et al. (1993a, 1993b, 1994) discuss the galactic center observations in some detail and give the OSSE results on the 0.511 MeV emission. Here, we comment on the status of discrete sources in the region.

The galactic center observations were undertaken with several different position angles of the OSSE 3.8^{o} x 11.4^{o} collimators with respect to the galactic plane (see Purcell et al., 1993b, for details). At low energies, the challenge for the OSSE team is to extract the diffuse and discrete components in a region where there is considerable source confusion. The approach for doing this is to undertake scans of the region at several position angles. Analysis of the data is complicated by the transient nature of many of the hard X-ray sources in the region. To assist in this task, we have undertaken several correlative observations with the GRANAT/SIGMA experiment. SIGMA can obtain hard X-ray and low-energy gamma-ray images, but at a sensitivity which is about 5 times poorer that the OSSE limiting sensitivity. Nevertheless, undertaking joint analysis of these data is proving very beneficial. We anticipate reporting soon on the first observations of the diffuse low-energy gamma-ray spectrum from the galactic center region in which contributions from simultaneous observations of discrete sources have been subtracted.

Jung et al. (1994a) report preliminary results for several of the sources in the galactic center region. These analyses use scanning techniques to "map" the diffuse and discrete sources in the galactic center region, and a background prediction technique to assist in estimating the background spectra for any given two-minute observation interval based on a global model of the OSSE instrument background and its time variations.

OSSE has detected several galactic center sources, including GX 1+4, 1E 1740.7-2942, GX 354+0, and GRS 1758-28. These have all been confirmed as SIGMA sources during several of the joint observations. Of particular interest are the gamma-ray spectra of the sources 1E1749.7-2942 and GRS 1758-28, each of which has been associated with a compact radio source which has opposing jets of radio emission extending from the compact source. These objects appear to be "stellar"-sized versions of active galactic nuclei, and are thought to harbor several solar mass black holes. 1E1740.7-2942 has been the object of considerable observation and theoretical interest following the report by SIGMA of an intense emission of red-shifted annihilation radiation during an outburst in October, 1990. (Bouchet et al. 1991) A similar enhancement in the 200-600 keV flux has been reported during September, 1992, although of lower intensity and at only the ~4σ level (Cordier et al. 1993). During this latter outburst, OSSE had a simultaneous observation, and does not confirm the reported increase in intensity (Purcell et al. 1994; Jung et al. 1994b). This raises some question about the reported outbursts of broad line features near 0.5 MeV for several galactic sources, and raises the importance of providing a positive observation with high significance. To date, OSSE has acquired in excess of 100 days of observing time on the galactic center region, including the 1E 1749.7-2942, and has not observed significant transient line features in preliminary data analysis (Purcell et al, 1993b)

For the OSSE data, preliminary spectra of the individual sources have been obtained. The quality of these results will continue to improve as the mapping studies provide an improved distribution of the diffuse hard X-ray continuum, thereby permitting improved extraction of the discrete source contributions.

6. Pulsars

OSSE has detected three radio pulsars in the low-energy gamma-ray band: the Crab Pulsar, the Vela Pulsar and PSR 1509-58. For pulsar observations, OSSE was operated in either an event-by-event mode or a rate mode to acquire high time resolution data. In the event-by-event mode the throughput is limited to about 200 counts/s and this restricts the energy range which can be investigated: the time resolution is either 1/8 ms or 1 ms. In the rate mode, broadband rates can be acquired in up to eight energy bands, with a best time resolution of 4 ms. For observations of the Crab pulsar and pulsars with comparable or shorter periods, the event-by-event mode is required. Preliminary results for the Crab pulsar were presented in Ulmer et al. (1992) and spectral and temporal results and will appear shortly (Ulmer et al. 1994).

OSSE observations of the Vela Pulsar have provided the first detection of low-energy gamma-ray emission from this object. The OSSE data, when compared with the high-energy gamma-ray spectrum, requires a spectral break in the 1-10 MeV region. Strickman et al. (1993) discuss the results and implications of this detection.

PSR 1509-58, a radio pulsar with a period of 150 ms, was first detected by BATSE (Wilson et al. 1992) in the low-energy gamma-ray region, and subsequently observed by OSSE during VP 23. The OSSE observations show a clear detection in the 50 keV to 1

MeV region (Matz et al 1994b). The spectrum is well represented by a power law with a spectral index of 1.69±0.08.

Geminga has recently been found to be both an X-ray pulsar (Halpern and Holt 1992) and a gamma-ray pulsar (Bertsch et al. 1992). OSSE observed Geminga for a total of three weeks in Phase 1; however, we have not found clear evidence for a pulsed signal. OSSE limits indicate that the spectral break required by a comparison of the X-ray and high-energy gamma-ray fluxes must occur above 1 MeV. The similarity between the X-ray and high-energy gamma-ray signatures of Geminga and the Vela pulsar suggests that additional observations of Geminga may lead to a positive detection by OSSE.

OSSE data have been used to search for gamma-ray emission from several millisecond pulsars with known periods, including PSR 1957+20 and PSR 1937+21. We find no evidence for gamma-ray emission from either object.

7. Other Galactic Sources

Several other galactic sources that OSSE has observed in Phase 1 include Nova Cygni 1992, and WR 140. Leising et al. (1993) present upper limits to the OSSE search for ^{22}Na emission from Nova Cygni. Additional observations of this source are being undertaken during Phase 3 due to the long half life of ^{22}Na and the possibility that Nova Cygni 92 was still optically thick to gamma rays at that time of the OSSE observation (Starrfield et al 1993)

Hermsen et al. (1994) have reported evidence for hard X-ray emission from WR 140, a Wolf Rayet star in a long period orbit with another supergiant. The hard X-ray emission could originate from electrons accelerated by shocks in the interacting winds of the two stars during periastron passage. Confirmation of this hypothesis will be strengthened if the emission is not observed in a future observation well removed from periastron in the system's 9-year orbital period.

8. Summary

OSSE has undertaken dedicated observations of over 30 galactic sources during the first two years of the *COMPTON* mission, detecting about half of them.. Several of these have been Targets-of-Opportunity following initial discovery by BATSE, demonstrating the complementary nature of the GRO instruments. GRO J0422+32, a transient black hole candidate was the strongest source observed by OSSE at 100 keV and excellent spectral and temporal observations have been presented. OSSE has also observed pulsars, the Vela pulsar and PRS 1509-58, previously undetected in low-energy gamma rays. During Phases 1 and 2, multiple observations were devoted to the galactic center region in support of a number of scientific objectives. Several sources in the galactic center region have been observed, and we anticipate providing the first results on the diffuse continuum emission in the low-energy gamma rays for which point source contributions have been subtracted.

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